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U1S S1820 S1834 S1839 S1854 S3048

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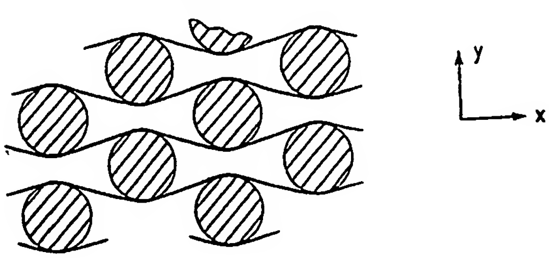
UK CL (Edition K) B5N
INT CL[5] B32B
WPI

(54) **Curvable core layers**

(57) Curvable sandwich panel cores of open ended cells with walls through the panel have re-entrant wall form to produce a negative Poisson ratio and thereby synclastic curvature by cell reshaping. Sandwich panels with synclastic curvature are formable using the cores. Six sided cells with a waisted form produced by opposed reflex inter-wall angles are one arrangement.

FIG. 1



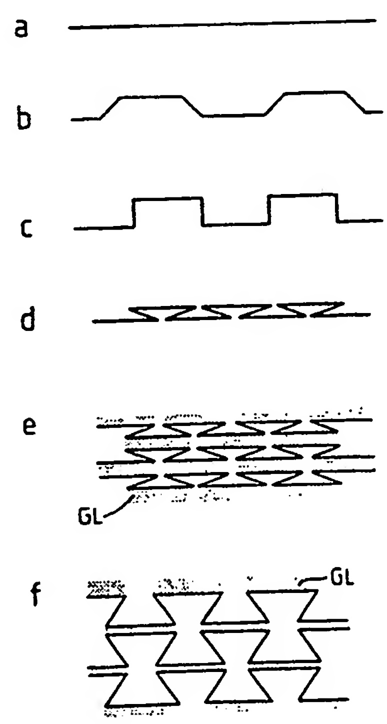


FIG. 12

FIG. 3

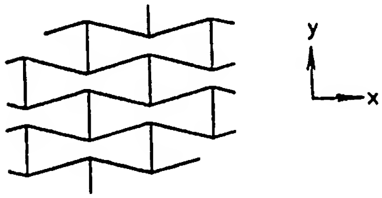


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FIG. 1

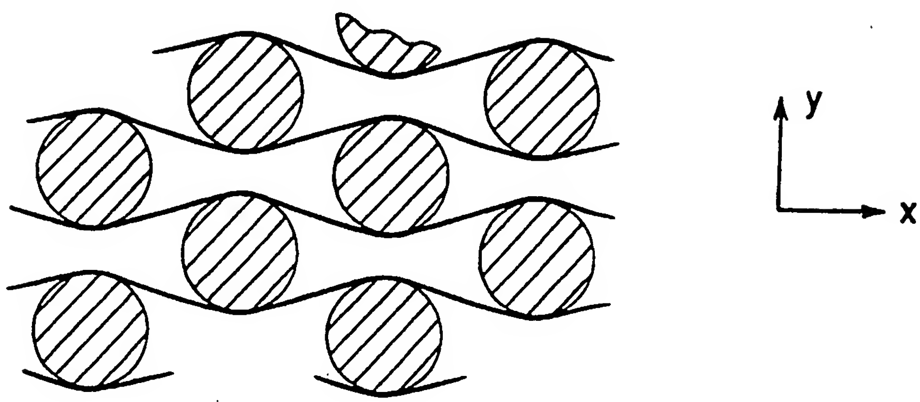


FIG. 2

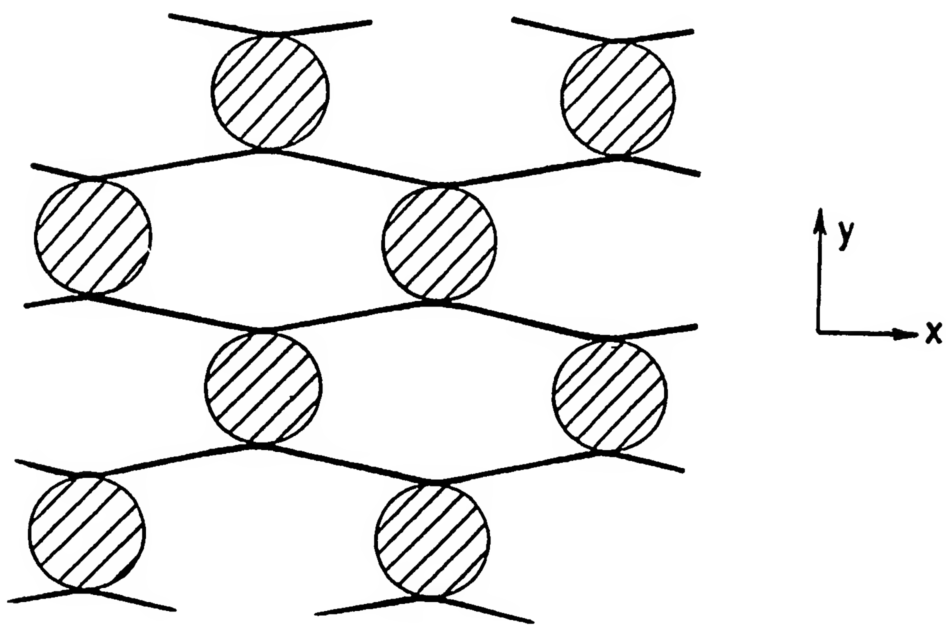


FIG. 3

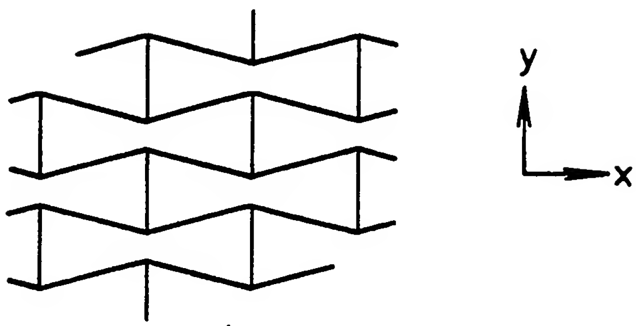


FIG. 4

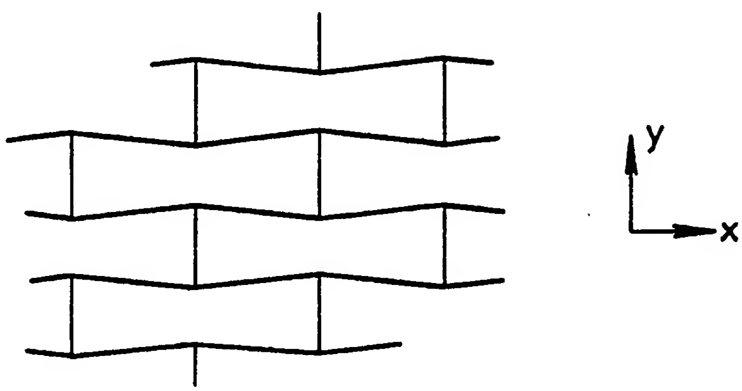


FIG. 5

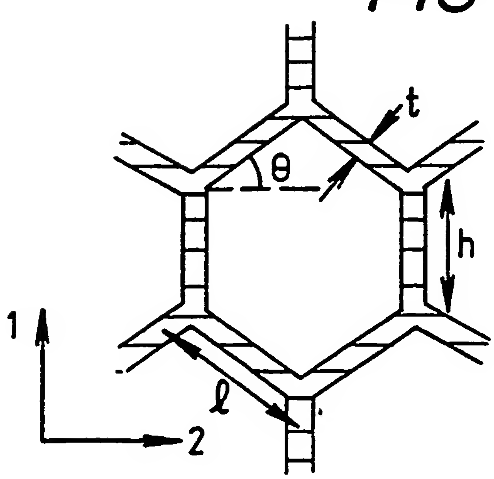


FIG. 6

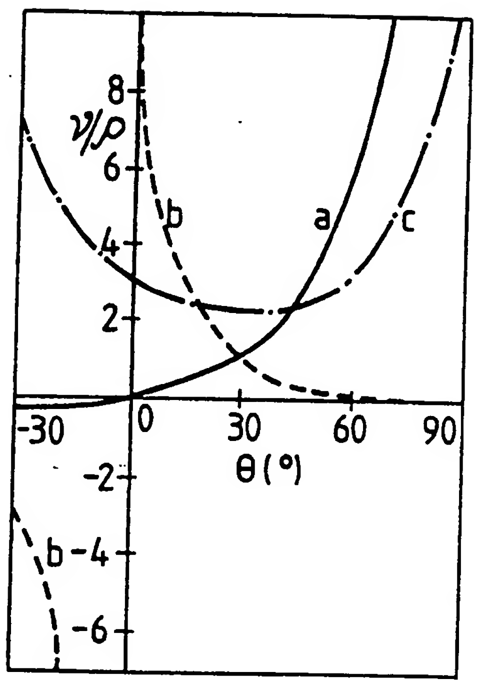


FIG. 7

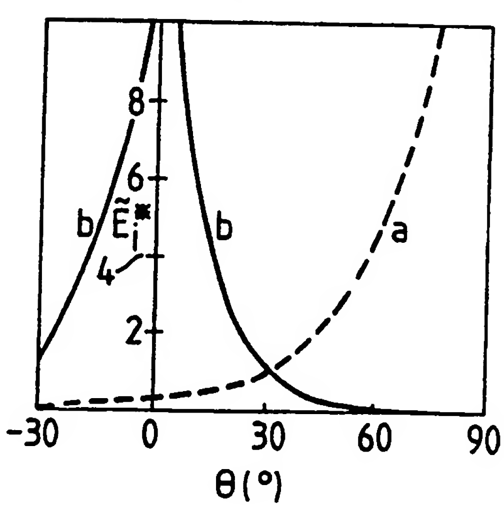
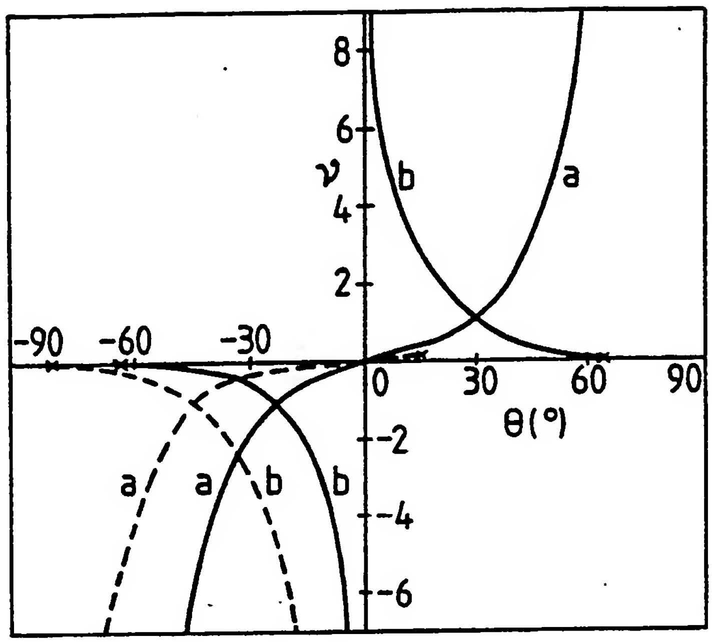


FIG.8


8
6
4
2
-2
-4
-6
ν
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-90
-60
-30
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30
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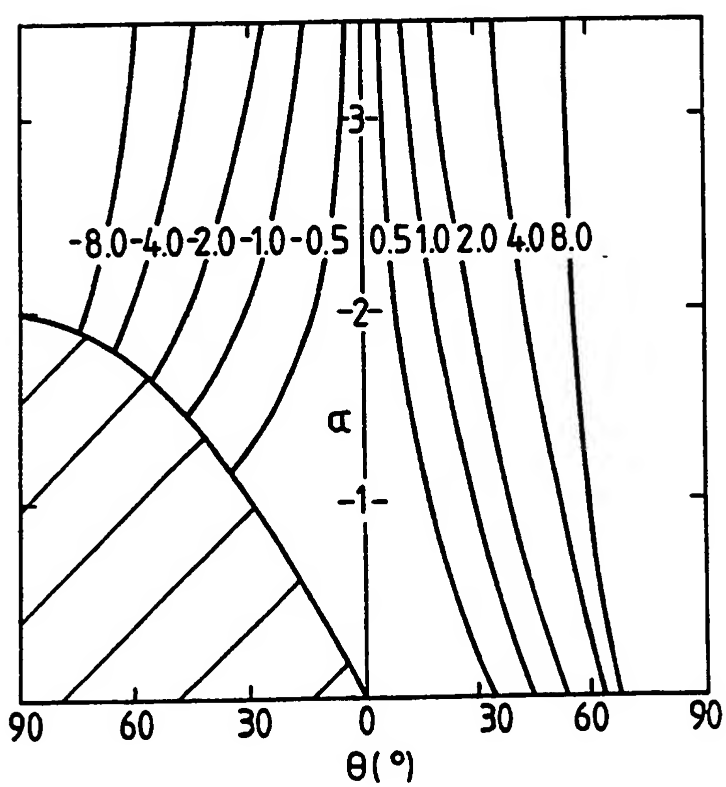
θ(°)
a
a
b
b

FIG.9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0.5
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θ(°)

FIG. 10

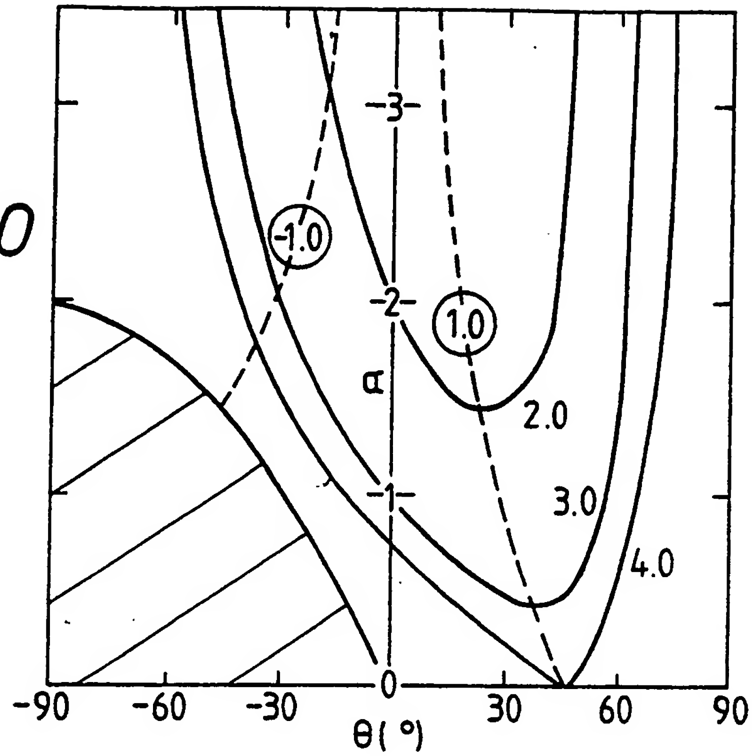
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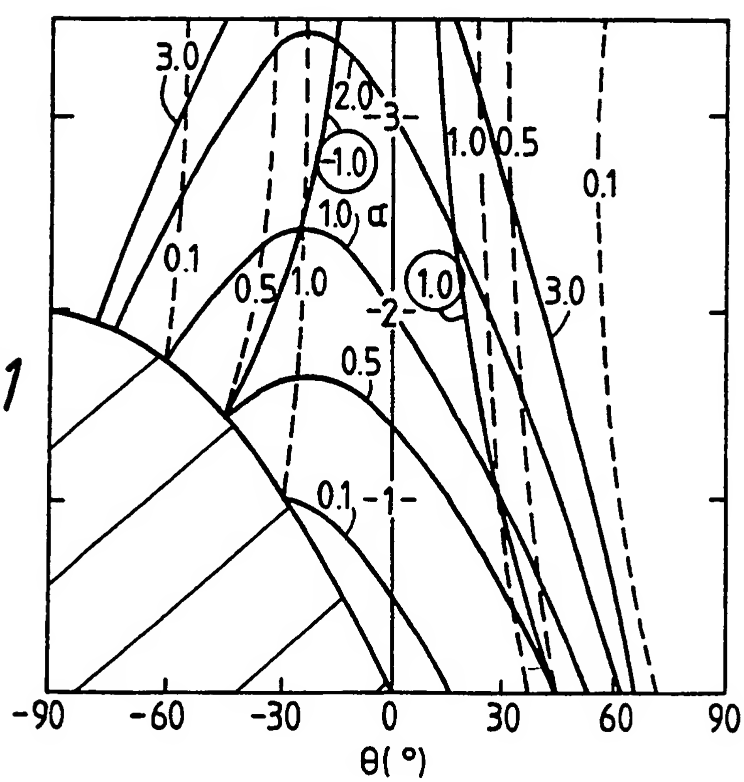
FIG. 11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θ(°)

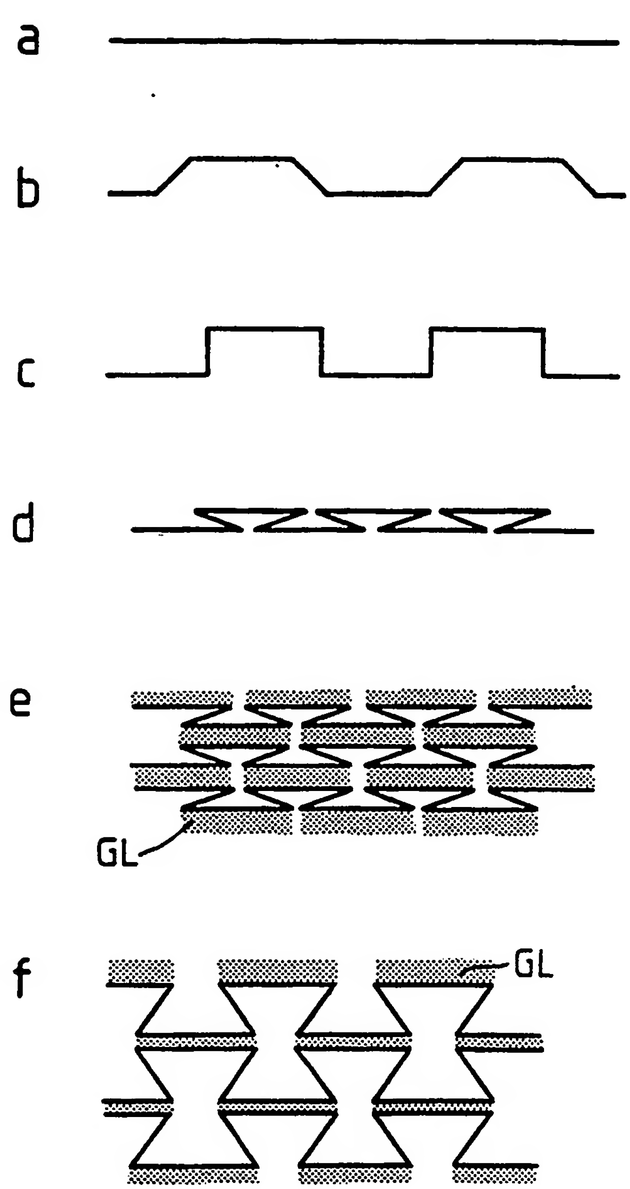

FIG. 12

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CORE LAYERS

This invention relates to the core layer of sandwich panels and to sandwich panels including such core layers.

A core layer used at present is of a form well-known in the art as "honeycomb" with regular hexagonal open-ended cells of convenient depth and is attached at the cell edges to a skin of a thin sheet to form the "sandwich". Generally there is one core layer with a skin on each opposite face, however variations are possible such as only one skin, on one face alone, or several skins and core layers, thus

skin|core|skin|core|skin.

Sandwich panels are widely used as strong, lightweight elements for fixed and movable constructions particularly vehicles for land, sea or air use. However hitherto such panels have generally been flat and this has limited the form of constructions including the panels. Curved constructions have been made by two expensive and not wholly satisfactory methods. A core layer can be forcibly curved, with inevitable distortion and damage by cell deformation, or a curved shape can be cut from a thicker layer, a tedious and wasteful procedure which anyway results in cells not perpendicular to the skin. Curved skins are then applied in either method.

It is an object of the present invention to provide panels not subject to this limitation.

According to the present invention there is provided a curvable core layer including cells with side walls and open ends, the cells of selected wall depth and with a re-entrant wall form.

Advantageously such cells reshape in form, that is without deformation, and remain perpendicular to the tangent at a cell-end on curvature of the layer. Reshaping can be by at least one of flexing and hingeing of the cell sides.

Cells of a re-entrant form can have at least one internal reflex angle. (A reflex angle is between 180° and 360°). Conveniently cells have six sides between angles but other numbers of sides from five upwards, with re-entrant cell form, are possible.

Conveniently individual cells are of waisted section, i.e. with opposed internal reflex angles, and are tessellated into the core layer. Generally all cells in a layer have the same depth.

Advantageously the re-entrant form permits shaping to a synclastic curvature. A negative Poisson ratio for the core layer permits such synclastic curvature. Synclastic curvature permits the "draping" of a core layer.

A synclastic curvature is one in which a curvature in one direction does not result in a transverse curvature in the opposite direction. One example of synclastic curvature is a doubly convex curvature.

Cells of re-entrant form permit a core layer to curve by "draping" while retaining cell integrity. Advantageously at least one of cell size and shape can be varied from place to place in the core layer to assist a particular curvature or drape.

The invention also provides a sandwich panel including a core layer having cells of re-entrant form and selected depth sandwiched between thin skins.

The skin material can have a negative Poisson ratio.

The invention further provides a method of producing sandwich panels with synclastic curvature.

The method includes assembling such panels from already curved components as well as shaping assembled panels.

When a material is stretched to become longer in one direction the dimensions of the material in other directions are usually reduced. The ratio of lengthening to reduction is called Poisson's ratio. However some materials have a negative Poisson ratio, enlarging in the other direction when stretched in the one direction.

Manufactured materials with negative Poisson ratio are uncommon. One such material is a foam based on metal and plastic open cell foams, for example of cell size around one millimetre, described in US Patent 4668557, inventor Roderic S. Lakes, and various papers by Roderic S. Lakes. The normal foam starting material is "transformed" by irreversible plastic deformations, e.g. by heating and application of pressure in all three perpendicular directions, to deform the ribs of the open cells to protrude inwardly. A characteristic of the plastically deformed Lakes material, stated to be consistent with negative Poisson ratio, is synclastic curvature. Synclastic curvature occurs when the curvatures across and along the principal direction of curvature are in the same sense. Material with positive Poisson ratio is stated to exhibit anticlastic curvature, that is the cross-wise curvature is opposite to that in the principal direction. Material with negative Poisson ratio produced by "transforming" foam is stated also to have superior strength, compliance and abrasion resistance and to be particularly suitable to replace conventional polymeric foams in various uses including sandwich panels.

However the Lakes foams are produced by "transformation" of existing open-cell foams and no other materials exhibiting negative Poisson ratio are described. All these materials are isotropic, having substantially the same characteristic in all three orthogonal directions. Lakes states that certain honeycomb structures have exhibited negative Poisson ratio in some directions, referring specifically to two theoretical treatments, (1) L.J. Gibson, M.F. Ashby, G.S. Schajer, and C.I. Robertson, "The mechanics of two dimensional cellular solids", Proc. Royal Society London, Vol. A382, 1982, pp. 25-42, (2) R.F. Almgren, "An isotropic three dimensional structure with Poisson's ratio = -1", J. Elasticity, Vol 15, 1985, 427-430.

The results quoted suggest a negative Poisson ratio but nothing exhibiting this is described. A two-dimensional planar structure based on rigid rods joined by elastic hinges is shown in Almgren and this is adapted, with struts and springs and simple hinges, to a three-dimensional isotropic structure. Gibson and Ashby in Cellular Solids, Pergamon 1988, at page 72 show a rubber model honeycomb with "inverted" cells which has a negative Poisson ratio. So far no design for a core layer having negative Poisson ratio has been provided in a form for actual use.

Embodiments of the invention will now be described with reference to the accompanying drawings in which:

Figures 1 to 4 show various honeycomb structures embodying the invention,

Figure 5 shows a diagram useful in understanding the invention,

Figures 6 to 11 show graphs useful in understanding the invention, and

Figure 12 shows a diagram of a method of making a core layer embodying the invention,

Figure 1 shows a structure, specifically a microstructure, of nodes at which fibrils are connected. The structure of Figure 1 is characterised by a re-entrant arrangement which, when the structure is subject to tension in the x direction, causes displacement in the y direction to expand the structure in the y direction (Figure 2). This is clearly a negative Poisson ratio. (Note that Figure 2 is only diagrammatic and may exaggerate the actual displacement in any particular structure.)

The structure of Figure 1 is useful as the interior filler, that is core layer, of structural sandwich panels. Figures 1 and 2 are from U.K. Patent Application 8916231.7 (inventor K.E. Evans and assigned to the assignee to whom the present Application is to be assigned).

By using a structure generally as shown in Figure 1 on the macroscopic scale with nodes at the joins between cell sides a "honeycomb" panel core layer of predictable negative Poisson ratio can be produced. Instead of the conventional honeycomb, with six substantially equal length sides and internal angles, now some internal angles are acute and some reflex, Figure 3, (a reflex angle is one that is between 180° and 360°) as in the Figure 1 structure. When subject to tension in the x direction expansion in the y direction occurs, again a negative Poisson ratio. The sides can be of different lengths.

An important feature of the arrangement shown is that local displacement of the layer out of the plane of the reflex angled honeycomb core layer can take place without damaging the cells, as would occur in the conventional, equal-angled, honeycomb. This follows from the synclastic nature of material with a negative Poisson ratio. Thus a sheet of reflex angled honeycomb embodying the invention can be curved to have lengthwise and crosswise curvature in the same direction, for example a dome-like form. This can not be achieved with the conventional equal angled honeycomb without the distortion and damage or machining operation mentioned above.

A consequence of this property is that a sandwich panel with lengthwise and crosswise curvature in the same direction can be produced.

This can be done either by first shaping the reflex angled honeycomb and the sheet skins separately and then joining them at the cell edges or by first assembling the reflex angled honeycomb to the sheet skins and then forming to the required shape, conveniently by heat and/or pressure. It may be that some stress is "built-in" to the panel but in general this is a useful effect. Furthermore the cells remain perpendicular to the tangent

at the cell-end, when the core layer is curved, improving the performance of the eventual sandwich panel.

It is an important advantage that a honeycomb arrangement according to invention, having re-entrant or more specifically reflex internal angles, can be designed with some areas of properties different from others. For example cell size, cell side lengths both overall and within a cell, and cell angles can be varied from part to part over the layer. In this way the ability of the layer to adopt curved shapes can be controlled and a required shape achieved with optimum performance. In particular the layer can be arranged to "drape" that is conform loosely to a shape, of varying and complex curvature, over which it is laid. Clearly the calculations for the shape, size and tessellation of the cells of such a layer will not always be easy but those skilled in the art will realise that a computer can be used to aid in the calculations. If required the material and construction at the nodes can be chosen to assist or achieve the ability of the material to conform to a shape.

The honeycomb with reflex internal angles can be constructed in various materials, such as those already known for conventional honeycombs. Specific techniques for constructing the honeycomb with reflex angles are described below.

By altering the geometry of the reflex angled honeycomb a range of values of υ can be provided, where υ is Poisson's ratio. Also similar effects can be produced for the sheet skins, which can be laminates, although this is sometimes more difficult.

Curvatures R_x and R_y, referred to below, are required synclastic curvatures of the core layer and are generally aligned with the axes 1 and 2 of Figure 5, in either possible way.

One detailed analysis of the mechanical properties of conventional two-dimensional cellular formations has been provided by the Gibson et al reference (1) above and the following equations 1 to 5 are from this reference with a slight change of notation. By assuming in this analysis deformation of the cellular units of the conventional honeycomb is due to deflection of the cell walls, acting like simple beams, it has been shown by Gibson et al that Young's moduli and Poisson ratios of this 2-D cellular material are given by:

$$E_1 = E_s \left(\frac{t}{\ell}\right)^3 \left[\frac{\alpha + \sin\theta}{\cos^3\theta}\right] \qquad (1)$$

$$E_2 = E_s \left(\frac{t}{\ell}\right)^3 \left[\frac{\cos\theta}{(\alpha + \sin\theta)\sin^2\theta}\right] \qquad (2)$$

$$\nu_{12} = \frac{\sin\theta}{\cos^2\theta} \left[\alpha + \sin\theta\right] \qquad (3)$$

$$\nu_{21} = \frac{\cos^2\theta}{\sin\theta} \left[\frac{1}{\alpha + \sin\theta}\right] \qquad (4).$$

The density of the honeycomb ρ is given by:

$$\frac{\rho}{\rho_s} = \frac{t}{\ell} \quad \frac{\alpha + 2}{2\cos\theta[\alpha + \sin\theta]} \qquad (5).$$

where t is the cell wall thickness, and $\alpha = (h/\ell)$ where h, ℓ and θ are defined in Fig. 5, E_s is the intrinsic modulus of the cell-wall material and ρ_s is its density, t/ℓ is assumed constant and in general $t>>\ell$.

Clearly analyses based on other equally-valid assumptions, for example hingeing at the nodes, will yield different mathematical expressions from which a design protocol can also be produced.

For convenience, consider the reduced variables:

$$E_1^* = \frac{E_1}{E_s}\left(\frac{\ell}{t}\right)^3 = \frac{\alpha + \sin\theta}{\cos^3\theta} \qquad (6)$$

$$E_2^* = \frac{E_2}{E_s}\left(\frac{\ell}{t}\right)^3 = \frac{\cos\theta}{\sin^2\theta[\alpha + \sin\theta]} \qquad (7)$$

$$\rho^* = \frac{2\rho}{\rho_s}\left(\frac{\ell}{t}\right) = \frac{\alpha + 2}{\cos\theta \quad [\alpha + \sin\theta]} \qquad (8),$$

υ_{12} and υ_{21} are defined as in equations (3) and (4).

Certain limited approximations are also worth quoting. For $\alpha >> 1$ we have $-90° \leqq \theta \leqq 90°$ and

$$\rho^* \approx \frac{1}{\cos\theta} \qquad (9).$$

When $\theta \to 90°$ beam stretching will become the dominant deformation mechanism, and this is not included in the model. In practice such an extreme angle is never used.

At the other extreme $\alpha \to 0$, $\theta \geqq 0$ is necessary since the cell walls are not to overlap. Under these conditions

$$\rho^* = \frac{2}{\sin\theta\cos\theta} \qquad (10).$$

Consider first a regular honeycomb where $\alpha = 1$. In Figure 6 the variation of (a) υ_{12}, (b) υ_{21} and (c) ρ^* are plotted against θ. The range of possible angles is $-30° \leqq \theta \leqq 90°$ otherwise cell wall overlap would occur. In fact the general range for a given α ($^h/_\ell$) value is

$$-[\arc\sin(^\alpha/_2)] \leqq \theta \leqq 90° \qquad (11).$$

Thus by a suitable choice of orientation a given ratio of relative curvatures $R_x/R_y = \upsilon_{12}$ or υ_{21} can be chosen. At the same time, of course, the density is varying and the specific moduli (a) $\tilde{E}_1^* = E_1^*/\rho^*$ and (b) $\tilde{E}_2^* = E_2^*/\rho^*$, as plotted in Figure 7 against θ for $\alpha = 1$, are also changing.

It is to be noted that the region $3 \leqq R_x/R_y \leqq 1/3$ is forbidden, because this structure is equal-sided, and this represents an important synclastic region. At $\theta = 30°$ we have a conventional hexagonal structure, which has a minimum density and isotropic properties. In fact it is easily shown, by differentiating equation (5), that when ρ is a minimum $\nu_{12} = 1$ for any relevant combination of θ and α given by the condition that

$$2 \sin^2\theta + \alpha \sin \theta - 1 = 0 \qquad (12)$$

From a design engineer's point of view it is more important to consider the range of curvatures and mechanical properties that may be achieved for a given structure density as weight constraints are often paramount where sandwich panels are used. This can be achieved by a simultaneous variation of θ and α. Hence equation (8) may be rearranged to give

$$\alpha = \left(\frac{2 - \rho_c^* \cos \theta \sin \theta}{\rho_c^* \cos \theta - 1} \right) \qquad (13)$$

where ρ_c^* is now the particular value of core density required. So for different values of θ the appropriate α ratio can be calculated. Figure 8 shows results for two particular densities, for the case of a conventional (regular) hexagonal structure, when $\rho_c^* = 2.309$ (solid line), and for the fully re-entrant (θ=-30°) version embodying the invention, when $\rho_c^* = 6.298$ (dashed line), for (a) ν_{12} and (b) ν_{21}.

Note that equation (13) also provides an additional limit on the values of θ that can be reached for a particular density, adding a further constraint to that imposed by the cell geometry. α must be positive hence

$$\rho_c^* \cos \theta \sin \theta \leqq 2 \qquad (14)$$

giving

$$\rho^* \sin 2\theta \leqq 4$$

hence

$$2\theta \leqq \arc \sin (4/\rho_c^*) \qquad (15).$$

From Figure 8 it can be seen that whereas $\rho_c^* = 2.309$ allows all values of R_x/R_y to be met $\rho_c^* = 6.928$ does not provide full coverage of the anticlastic curvature range. The limiting density to meet this requirement is when the two curves for ν_{12} and ν_{21} first meet. In other words at this limit value $\nu_{12} = \nu_{21}$. At this point the limit value of θ given by $\theta = (\arcsin {}^4/\rho_c^*)/2$, which is the limit of $\alpha \to 0$. At this point, $\alpha \to 0$, $\tan^2\theta = 1$ so $\theta = 45°$ giving $\rho_c^* = 4$ as the maximum density required to give full coverage of the R_x/R_y ratio, by a suitable choice of either ν_{12} or ν_{21}. Below this density it is possible to find two configurations with isotropic properties, one of which has a positive ν value of +1 and one with a negative $\nu = -1$ value. For $\rho_c^* = 2.309$ the positive isotropic case is a regular hexagon, whereas the negative isotropic case has $\theta = -22.5°$ and $\alpha = 2.484$.

Figures 9 to 11 are contour plots of important design variables as a function of the honeycomb geometry variables. In each of these the hatched region is forbidden by cell geometry constraints. Thus the free variables are the cell aspect ratio α and the cell angle θ (see Figure 5). Figure 9 provides a contour plot of various values of ν_{12} as functions of θ and α.

A choice of geometries is therefore available to give, say, a particular value of ν_{12}. Similarly equivalent density contour plots for ρ^* are shown in Figure 10. Since there are two independent geometric variables it is possible to find a geometry that will satisfy a particular combination of density and Poisson ratio. For example with $\nu_{12} = -1$, for an equicurved synclastic panel, the dashed line on Figure 10 shows the particular geometric parameters required for certain combinations of ν_{12} and density. Note also the dashed line for $\nu_{12} = +1$ lying along the density minimum as described by equation (12). Finally contour plots, against θ and α, in solid and dashed lines respectively for

$\tilde{E}_1^*$ and $\tilde{E}_2^*$ are given in Figure 11. Again the values $\nu_{12} = \pm 1$ are also included. This represents the condition for isotropy in the system and represents the function of equal $\tilde{E}_1^*$ and $\tilde{E}_2^*$ contours.

Some general points can be raised concerning these plots. First, for $\alpha>3$ the mechanical properties and density become very slowly varying functions of the α ratio (i.e. nearly vertical, parallel contours). In any case higher values of α produce impractical cell structures. Secondly, for large values of α all the properties become symmetric functions of θ but in the range of interest they can be highly asymmetrical.

Thus by a suitable choice of geometric parameters it is possible to produce a two-dimensional honeycomb embodying the invention with varying degrees of double curvature of the useful synclastic case. In principle, skin structures based on unidirectional laminates can also be designed with matching curvatures by tailoring the properties but this usually results in added twist and shear complications, or would require materials with elastic constants in a range not currently available.

The re-entrant honeycomb core is deformed elastically so it will not, of its own accord, remain doubly curved. However, providing the honeycomb is held in shape while the skins are bonded to it they will hold the panel in shape after curing. The skins will generally have much higher in-plane moduli than the core and will of necessity be well bonded to it. Indeed, in some situations the stored elastic energy of the deformed core can act to increase the apparent stiffness of the curved panel. Plastic deformation of the honeycomb may be useful in some situations.

Tailoring the geometry of the re-entrant angled honeycomb core to provide a particular degree of synclasticity also affects its other mechanical properties. This has been illustrated by the case of the in-plane Young's moduli. Other properties will

also vary, such as the shear modulus, the flexural properties and also the buckling instability of the panel. However for each of these an equivalent contour plot to those of Figures 9 to 11 can be plotted. The optimum combination of these properties is then found by determining the point on a plot of α against θ that is the shortest distance from all the appropriate contours.

While interesting theoretical honeycomb forms may be postulated these are only of practical industrial use if they can be made. One method of making a re-entrant core layer embodying the invention is now described. A sheet of metal, such as aluminium alloy, is passed through a series of dies and rollers which convert the sheet into a multilayer, lengthwise-folded form which can be assembled with similar forms and then expanded into a cellular structure. Figure 12 shows in a simplified diagrammatic way this method. At stage (a) is the flat sheet and at stage (b) the first die stage, producing horizontal elements at least twice as wide as each inclined element. At stage (c) a further die stage has further formed the strip in preparation for the die stage shown in (d) where the fully-folded elements link the surface elements and are covered by them. At this point the folded strip can be put through a pair of rolls to compact it. Stage (e) shows several strips from stage (d) assembled with adhesive GL on the surface elements to form a stack. At stage (f) the stack has been expanded by any suitable means such as tension or fluid pressure to produce a core layer with re-entrant cells. In practice the strip would be much wider and longer than shown and the stack formed can be sliced, by cuts parallel to the plane of the drawing, for expansion into core layers of open-ended cells of selected depth and with a re-entrant form. Other methods than glueing, for example welding, may be used to assemble the stack.

With more difficult production the sheet at stage (d) can have horizontal elements less than the total width of the inclined ones, the difficulty arises in that the sheet is not flat, the inclined elements overlapping.

An alternative method of production is a step-by-step progress along the material, for example by feeding a strip through a stamping press, to form the elements across the material in one or more stages. Several strips are then assembled in any convenient way to produce the re-entrant core layer. As the strips can be any required length and stacked to any required number very large core layers can be made, albeit limited in thickness by the strip width, but this is unlikely to be a problem for core layers.

Further methods of production include moulding and stamping. Thus a conventional thermoplastic material may be shaped in a mould from a fluid state or a suitable plastic foamed in place in a mould. Foamed plastics in particular can be formed with thick walls to the cells to give stiffness without a weight penalty. Another method is to stamp the structure from a sheet of material of appropriate thickness. Whatever method is used the cells can be shorter (undersquare) or taller (oversquare) than their cross-section.

Although described specifically for cells of six sides the techniques are not limited to such cells, nor to structures in which all cells have the same number of sides, provided the cell can accomodate a re-entrant. Furthermore only some cells in a structure need have a re-entrant if the required Poisson ratio property is achieved.

Where sides are referred to these can be curves rather than straight lines and the number of sides then less well-defined. A cell arrangement is possible with relatively thick walls, that is t not less than ℓ (the general case referred to above being t very much less than ℓ). For example opposed sinuous wall portions arranged to altrnately converge and diverge can provide the re-entrant parts of the cells, with straight wall portions joining the opposed sinuous portions at their greatest

divergence. The junctions of the walls may be smoothly curved and thickened but wall thickness is generally uniform. All the variations such as shape, size, wall length mentioned above may be used where appropriate to produce required synclastic curvatures.

To control the curvability of the core layer cell-size or shape can be varied from part to part of the layer. To achieve this one or more of the dies can have a controllably non-uniform shape to alter the size of the folded elements and thereby the cells. While the above method produces cells with four sides shorter than the other two sides such cells are quite satisfactory.

The techniques described above permit the production of a doubly-curved core, and thus a sandwich panel, with curvatures R_1 and R_2 (in the sense of Figure 5) where R_2 is the result of Poisson ratio when curving to radius R_1. Curvature R_2 can be varied by control of the Poisson ratio provided by the above techniques.

The techniques described above provide stiffening material layers and sandwich panels including such layers with a capability of synclastic curvature, such as a capacity to "drape".

CLAIMS

1 A curvable core layer including cells with side walls and open ends, the cells of selected wall depth and with a re-entrant wall form.

2 A core layer according to Claim 1 in which said re-entrant cell form is produced by cell sides with angles therebetween, the angles including at least one internal reflex angle (an angle between 180° and 360°).

3 A core layer according to Claim 2 having cells with at least five sides between angles.

4 A core layer according to Claim 2 having cells with six sides between angles.

5 A core layer according to Claim 4 with opposed internal reflex angles.

6 A core layer according to Claim 1 in which individual cells are of waisted section, and are tessellated into the core layer.

7 A core layer according to Claim 1 in which all cells have the same selected depth.

8 A core layer according to Claim 1 in which some cells differ from others in at least one of size and shape.

9 A core layer according to Claim 1 capable of a synclastic curvature.

10 A core layer according to Claim 1 having a negative Poisson ratio.

11 A core layer according to Claim 1 with cell wall thickness, length, density and direction chosen and related to produce a negative Poisson ratio.

12 A core layer according to Claim 1 in which cells reshape in form and remain perpendicular to the tangent at a cell-end on curvature of the layer.

13 A core layer according to Claim 1 in which reshaping is by at least one of flexing and hingeing of the cell sides.

14 A drapable honeycomb core layer including cells of a re-entrant form.

15 A sandwich panel including a core according to Claim 1 and at least one skin attached to the core cell edges.

16 A sandwich panel according to Claim 15 in which said at least one skin has a negative Poisson ratio.

17 A synclastically curved sandwich panel including a sandwich core layer of cells with walls extending between sandwich skins.

18 A sandwich panel according to Claim 17 in which said cells are perpendicular to the panel at a said cell.

19 A method of producing a core layer for synclastic curvature including:

assembling a layer of cells with walls through the panel and open ends, the cells having a re-entrant form,

controlling the production of the cells of re-entrant form in terms of at least one of size and shape to determine a negative Poisson ratio appropriate to a required synclastic curvature,

20 A method of producing sandwich panels with synclastic curvature including:

providing a sandwich core layer of cells with walls through the panel and open ends, the cells having a re-entrant form,

controlling the production of the cells of re-entrant form in terms of at least one of size and shape to determine a negative Poisson ratio appropriate to a required synclastic curvature,

providing at least one sandwich skin,

assembling the core and said at least one skin as said panel,

causing or permitting the synclastic curvature at least when the assembly is complete.

21 A method according to Claim 20 including assembling such panels from already curved components.

22 A method according to Claim 20 including shaping assembled panels.

23 A core layer substantially as herein described with reference to the accompanying drawings.

24 A method of making a core layer substantially as herein described with reference to the accompanying drawings.

25 A sandwich panel substantially as herein described with reference to the accompanying drawings.

24 A method of making a sandwich panel substantially as herein described with reference to the accompanying drawings.

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